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## Technical Memorandum 78091

# Hand-held Radiometer Red and Photographic Infrared Spectral Measurements of Agricultural Crops

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AND PHOTOGRAPHIC INFRARED SPECTRAL  
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**HAND-HELD RADIOMETER RED AND PHOTOGRAPHIC INFRARED  
SPECTRAL MEASUREMENTS OF AGRICULTURAL CROPS**

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ABSTRACT

Red and photographic infrared radiance data, collected under a variety of conditions at weekly intervals throughout the growing season using a hand-held radiometer, were used to monitor crop growth and development. The vegetation index transformation was used to effectively compensate for the different irradiational conditions encountered during the study period. These data, plotted against time, compared the different crops measured by comparing their green leaf biomass dynamics. This approach, based entirely upon spectral inputs, closely monitors crop growth and development and indicates the promise of ground-based hand-held radiometer measurements of crops.



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# HAND-HELD RADIOMETER RED AND PHOTOGRAPHIC INFRARED SPECTRAL MEASUREMENTS OF AGRICULTURAL CROPS

## INTRODUCTION

The research described herein was undertaken to determine if ground-collected hand-held radiometer red and photographic infrared (ir) spectral measurements, collected under a variety of field and irradiational conditions at weekly intervals, could be used to make qualitative and/or quantitative inferences about the various agricultural crops measured. Basic to this objective was the evaluation of simple radiance transformations which were used to avoid having to make sun angle corrections, atmospheric adjustments, and solar irradiance compensations.

A secondary objective of the research was to investigate the usefulness of monitoring the green leaf area or biomass through time. It is apparent that the green leaf material present in the crop canopy is where the photosynthetic activity occurs. Thus, by monitoring the green leaf area or biomass, inferences could be made regarding crop growth and development. Environmental conditions which adversely affect photosynthesis could possibly be spectrally inferred as they also affect the green leaf biomass. Simply stated, the green leaf biomass, driven by biotic and abiotic variables, produces the photosynthates which are then allocated by the plant in question for growth, seed or grain development, etc.

Red and photographic ir spectral measurements are ideally suited for monitoring the green leaf area or biomass (Tucker 1978). Therefore, if some straightforward means of normalizing for different irradiational conditions could be employed, red and photographic ir radiance data could possibly be used to nondestructively monitor the green leaf biomass throughout the growing season.

The majority of remote sensing research efforts to date have either used Landsat data (NASA 1973a; NASA 1973b; Williams and Carter 1976; Short et al. 1976; among others) or have, to a lesser extent, used laboratory leaf spectra (Gausman et al. 1976; Olson 1967; among others), or ground-based in situ spectrometer data (Kanemasu 1974; Miller et al. 1976; among others). In situ data is invaluable for research purposes and as a means of better understanding satellite imagery of the earth's surface.

Ground-based in situ spectrometer studies have often suffered from the usual cumbersomeness of these instruments and the resulting lack of mobility and spatial coverage. These are compensated for, however, by the detailed spectral measurements obtainable from these instruments.

A new approach has been developed for overcoming the limitations of the ground-based in situ spectrometer studies. This involves the deployment of hand-held spectral radiometers and was first reported by Pearson and Miller (1972). The hand-held radiometer approach results from and is closely associated with detailed in situ spectrometer studies.

Detailed in situ spectrometer data are used to determine what wavelength regions are of interest to the task at hand. When this objective has been completed, a simple hand-held radiometer can be used with custom-made interference filters configured exactly to the in situ spectrometer results. An example of the detailed in situ spectrometer analysis would be Tucker and Maxwell (1976). The resulting hand-held radiometer device is illustrated by Pearson et al. (1976).

Hand-held radiometers can be used to adequately cover the spatial variability present in the research task at hand. They are light, sturdy, and have many applications because of their mobility. Because of these factors, they can be used to collect basic data about vegetated surfaces in a controlled experimental setting. This will greatly increase the in situ knowledge about remote sensing of vegetation and serve as the basis for more rational usage of remotely sensed information. It should also discourage or prevent overly ambitious applications of remote sensing when no causative relationship exists for the particular task at hand.

#### PREVIOUS RELATED WORK

Remotely sensed spectral radiance and reflectance data has been used in an attempt to temporally monitor vegetative conditions for several cover types. Rouse et al. (1974) used Landsat MSS data from the American Great Plains to assess the green-wave effect from that area. They found that although a simple ratio of MSS7/MSS5 ( $MSS7 = 0.80 - 1.10 \mu m$  and  $MSS5 = 0.60 - 0.70 \mu m$ ) could

be used as a measurement of relative greenness, location, cycle, and atmospheric deviations would introduce a large error component. The difference of the MSS7-MSS5 radiance values, normalized over the sum of MSS7 and MSS5, was used as an index value and was christened the vegetation index (VI) in order to minimize this error component.

Carnegie et al. (1974) used a MSS7/MSS5 ratio and found that the ratio curves, plotted as a function of time, peaked during the period of greatest forage production. Thereafter, the curves fell off signalling the period of drying following the maximum green period for their California study sites.

Blair and Baumgardner (1977) monitored several hardwood forest sites using Landsat imagery. They used the VI, which they refer to as the "band ratio parameter," and found that the greenwave effect could be monitored for these vegetation types using Landsat imagery.

Ashley and Rea (1975) reported how Landsat MSS5 and MSS7 data was used to depict phenological change. They also used the VI and found that it increased with foliage development and decreased with senescence. The VI was found to reduce influencing multiplicative effects such as solar elevation differences between overpasses (Ashley and Rea 1975).

The majority of seasonal remote sensing studies have used Landsat data because of the 18 day repeat cycle. Kanemasu (1974), however, reports on one

of the few published ground-based reflectance studies of crop types. He monitored wheat, sorghum, and soybean plots periodically during the growing season using a spectrometer. Kanemasu (1974) concluded the 0.545/0.655  $\mu\text{m}$  wavebands provided useful information regardless of crop type. For all crops studied, the ratio closely followed crop growth and development and appeared to be more desirable than the near-infrared reflectance as an index of growth.

Tucker (1978) has reported on in situ grass reflectance studies for a period of high and predominately (80%) green biomass (June), a period of high biomass with 50% green and 50% standing dead biomass (early September), and a period of completely dead standing biomass (mid-October). The VI was found to be the most useful of any of the reflectance variables evaluated and was closely related to the green leaf biomass.

The majority of seasonal remote sensing studies have used red and photographic infrared data. The green/red ratio reported by Kanemasu has been found by most workers to be less useful than the ir/red ratio or a related transformation such as the VI. The reason for this is simply that the VI or ir/red ratio combines two different coupled effects.

The red reflectance of green crops over a soil background is less than exposed soil of the same soil-type because of chlorophyll absorption while the ir reflectance (  $\sim 0.74\text{--}1.00 \mu\text{m}$  ) for green crops is greater than the exposed soil surface because of enhanced reflectance occurring in the absence of absorption.

Hence a ratio of these two reflectance variables, or an associated transformation such as the VI, tends to compensate for differences in the soil background spectra (Colwell 1974) while containing information about the chlorophyll-green leaf biomass interaction. The green reflectance ( $\sim 0.50\text{--}0.60\ \mu\text{m}$ ), by comparison, does not have the same green vegetation — soil reflectance contrast as the red or photographic infrared reflectances (Fig. 1). This results from the fact that the chlorophylls are slightly absorptive (absorption coefficient =  $\sim 7$ ) in the green region with no appreciable absorption in the  $\sim 0.74\text{--}1.00\ \mu\text{m}$  region. The red region, by contrast, has chlorophyll absorption coefficients on the order of 40 to 90 (Salisbury and Ross 1969).

The same information about the chlorophyll concentration is thus more strongly evident in the red than green regions of the spectrum. Because the chlorophylls absorb an order of magnitude greater in the red than green region, a much greater soil-green vegetation reflectance contrast exists in the red region (Fig. 1). For these reasons, the majority of Landsat investigators, where the greatest amount of remote sensing of vegetation research has been done, have used the red (MSS5) and ir (MSS6 or MSS7) bands in their analyses. The Landsat green band (MSS4) has not seen nearly as widespread vegetational usage as MSS5 and MSS6 or MSS7 (Rouse et al. 1974; Carneggie et al. 1974; Ashley and Rea 1975; Blair and Baumgardner 1977; among others).



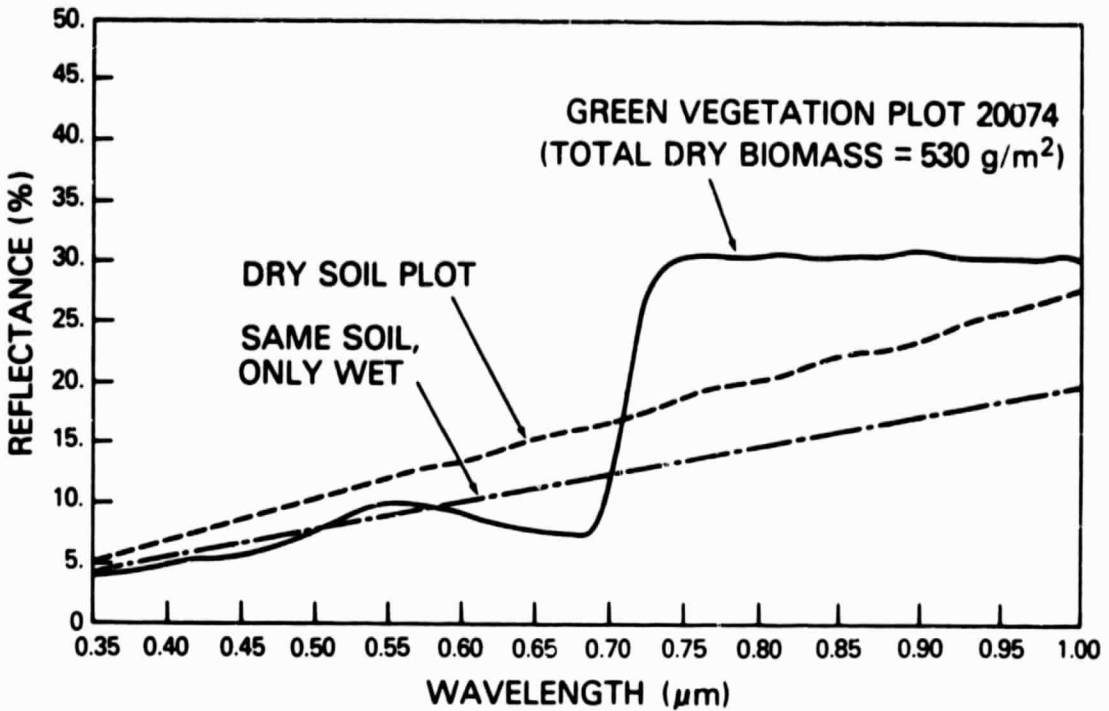


Figure 1. Spectral reflectances for dry soil, wet soil, and the asymptotic green reflectance. The dry soil and wet soil are for the same soil type where five exposed soil plots of each were measured dry and wet, respectively. The asymptotic green reflectance curve is from a plot of blue grama grass having a total dry biomass of  $530 \text{ g/m}^2$  (from Tucker and Miller 1977).

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## METHODS — LOCATION

### Study Locations and Data Used

A field of Elinsboro sandy loam soil located on the USDA Beltsville Agricultural Research Center was selected for this study. Fourteen 6 x 6 m plots each of corn and soybeans were planted as were four 6 x 6 m alfalfa plots. In addition to the 6 x 6 m plots, four 6 x 6 m areas each were selected from larger corn and soybean fields and six 1 x 6 m areas were selected from a large alfalfa field. Agronomic notes pertaining to growth stage (crop calendar), percentage ground cover, and plant height were taken weekly throughout the growing season for all the plots. Spectral measurements were also attempted at seven day intervals, although the actual time between spectral measurements varied from 4 days to 12 days depending upon the weather. In addition, at biweekly intervals, spectral and agronomic measurements were made on corn and soybeans in selected areas in the larger fields prior to taking destructive total wet and total dry biomass samples. The alfalfa field was destructively sampled in the same way at weekly intervals. Refer to Table 1 for additional details on the experimental layout and sampling procedure.

### Instrumentation and Operation

A hand-held digital radiometer was used to collect the red and photographic ir radiances used in this study (Pearson et al. 1976). Multiple readings were made within each experimental plot and averaged to account for the spatial variability. Refer to Table 1 for the number of readings taken per plot. Prior to

Table 1

Description of Crop Types, Plot Size and Location, and Other Related Factors for the Three Crops Reported Herein

| Crop    | Plot Size | Number of Plots           | Number of Readings Per Plot | Location                          | Duration  | Purpose                                                           |
|---------|-----------|---------------------------|-----------------------------|-----------------------------------|-----------|-------------------------------------------------------------------|
| Alfalfa | 6 x 6m    | 4                         | 30                          | Small plot field; east of US 1    | June-Oct. | Weekly nondestructive measurements; harvest data every 5-6 weeks. |
| Alfalfa | 1 x 6m    | 3                         | 10                          | Large alfalfa field; east of US 1 | Aug-Sept. | Weekly nondestructive measurements; harvest data after 5th week.  |
| Alfalfa | 1 x 6m    | 3 different plots/week    | 10                          | Large alfalfa field; east of US 1 | Aug-Sept. | Spectral and biomass measurements every week.                     |
| Alfalfa | 1 x 6m    | 3 different plots/week    | 10                          | Large alfalfa field; east of US 1 | July-Aug. | Spectral and biomass measurements every week.                     |
| Corn    | 6 x 6m    | 12                        | 24                          | Small plot field; east of US 1    | June-Oct. | Weekly nondestructive measurements; harvest data in October.      |
| Corn    | 6 x 6m    | 4                         | 24                          | Large corn field; west of US 1    | June-Oct. | Weekly nondestructive measurements; harvest data in October.      |
| Corn    | 6 x 6m    | 4 different plots/14 days | 24                          | Large corn field; west of US 1    | June-Oct. | Biweekly spectral and biomass measurements.                       |
| Soybean | 6 x 6m    | 12                        | 16                          | Small plot field; east of US 1    | June-Nov. | Weekly nondestructive measurements; harvest data in November.     |
| Soybean | 6 x 6m    | 4                         | 16                          | Large soybean field; west of US 1 | June-Nov. | Weekly nondestructive measurements; harvest data in November.     |
| Soybean | 6 x 6m    | 4 different plots/14 days | 16                          | Large soybean field; west of US 1 | June-Nov. | Biweekly spectral and biomass measurements.                       |

each series of spectral measurements on a given plot, a solar intensity calibration reading was taken from a  $\text{BaSO}_4$  panel. All measurements were made normal to the canopy surface between 1000 and 1500 hours on generally clear days.

The individual red and photographic infrared readings were transformed into the ir/red ratio, the ir-red difference, the ir + red sum, the vegetation index (VI) of  $(\text{ir}-\text{red})/(\text{ir} + \text{red})$ , and transformed vegetation index (TVI) of  $\sqrt{\text{VI} + 0.5}$  (the VI and TVI are after Rouse *et al.*, 1974). Each of the seven spectral variables were evaluated for the radiance data and the reflectance data. Reflectance was determined by dividing the plot radiance measurements by the  $\text{BaSO}_4$  reference measurements.

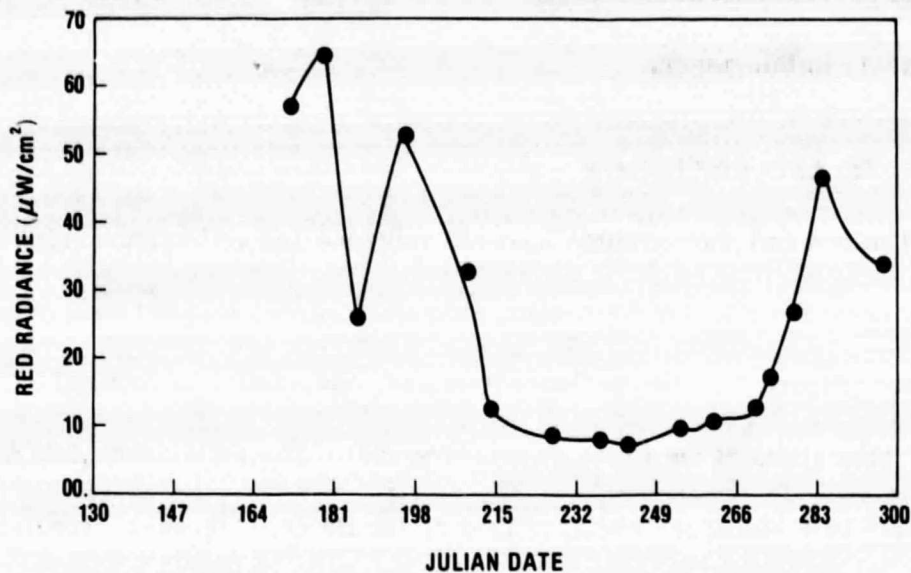
The data values presented subsequently in this article are typical results from the study. Generally, the radiance variable results will be presented because they represent the uncalibrated data which is similar to what is viewed from aircraft and/or satellite platforms. Reflectance results will only be presented where appropriate. It should be noted that the same types of remotely sensed data can be somewhat adequately collected by the Landsat 1, 2 and C multispectral scanner (MSS) system bands MSS5 and MSS6 or MSS7. Landsat-D, scheduled for launch in 1981, will provide much superior data from its thematic mapper (TM) scanner system than has been obtained from Landsats 1, 2, and C. Thematic mapper bands TM 3 ( $0.63\text{--}0.69\ \mu\text{m}$ ) and TM 4 ( $0.76\text{--}0.90\ \mu\text{m}$ )

should provide excellent satellite data for the same types of purposes as the data presented in this paper.

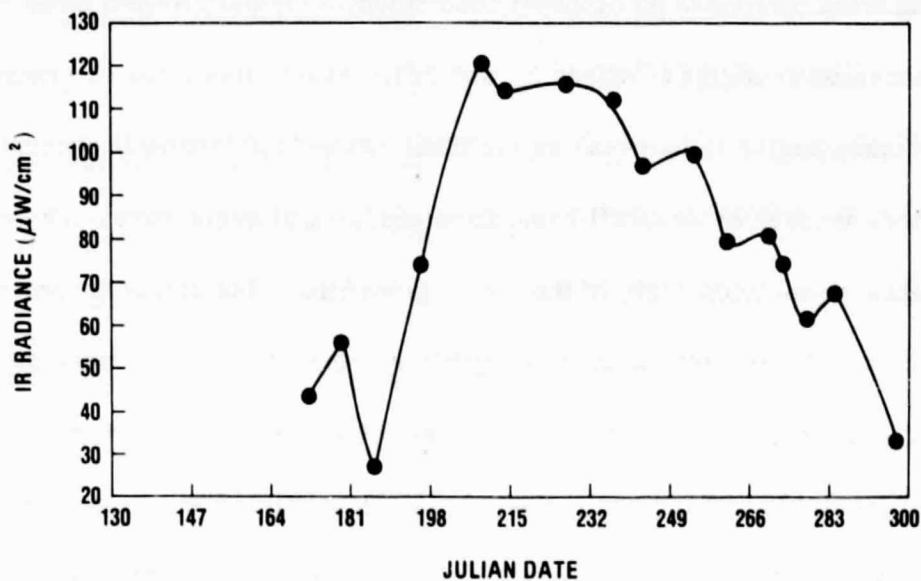
## RESULTS AND DISCUSSION

The red and photographic infrared radiance and reflectance values quantitatively show the effect of increasing amounts of green leaf biomass over the soil surface (Figure 2). The radiance data show the scatter introduced by varying solar intensities at the times of measurement. The reflectance data have been adjusted by dividing the radiance data by the  $\text{BaSO}_4$  reference (irradiance) data.

The red radiance and reflectance data show a rapid decrease with time, resulting from increased chlorophyll absorption, until the growing season wanes and senescence begins (Figures 2A and 2C). At this time, the red radiance and reflectance begins to increase as the plant canopy's chlorophyll concentration is reduced, through chlorophyll breakdown and/or leaf dehiscence. The red reflectance asymptotes early in the growing season. This can be interpreted in two ways: The red reflectance asymptote has been reached because additional green leaf biomass lower in the canopy would not receive any incident red light (i.e., the red light has been extincted via chlorophyll absorption) or the various abiotic and biotic variables, other than light penetration, controlling plant growth and development have become limiting. These conditions then limit the amount of green leaf biomass present. The data presented in Figure 2 represent the red light extinction situation.

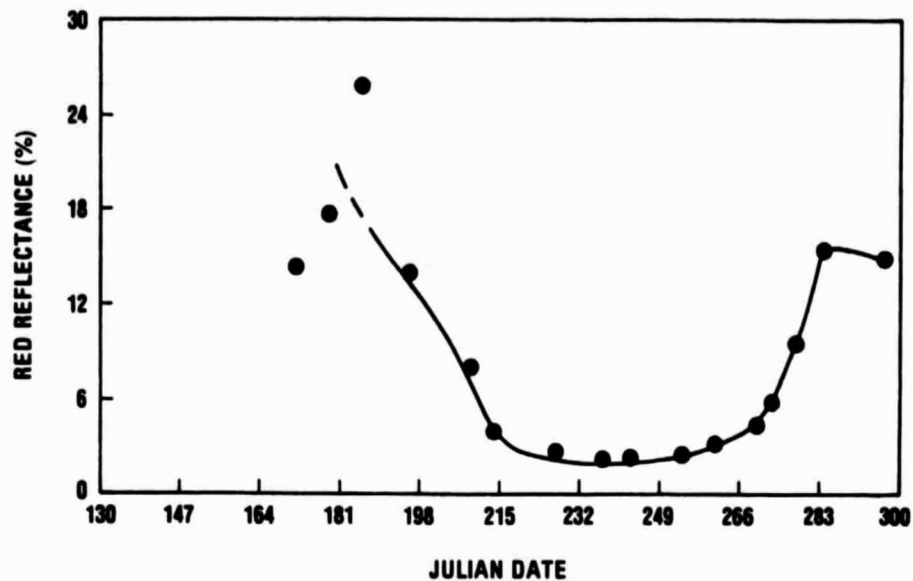


(A)

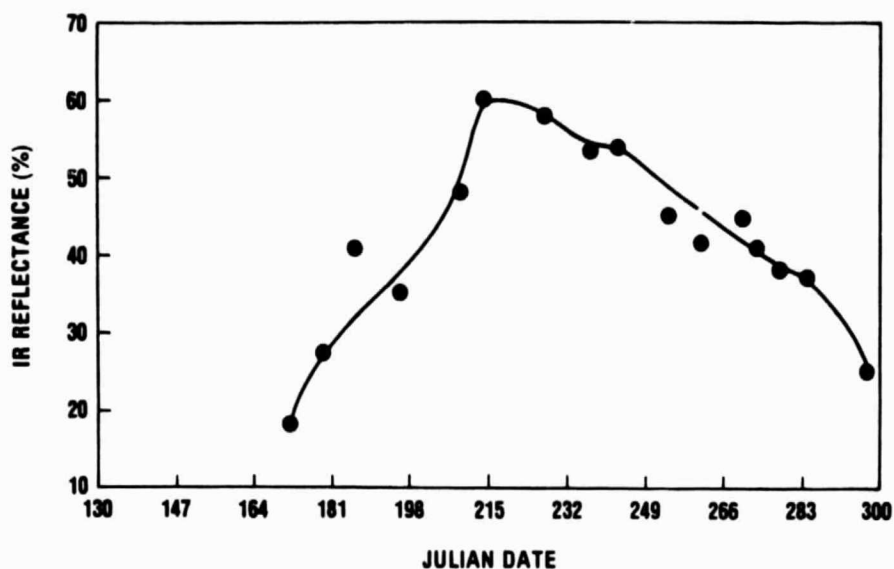


(B)

Figure 2. Red and photographic IR radiances and reflectances plotted against Julian date for a typical soybean experimental plot. Plotted against Julian date are (A) red radiance, (B) ir radiance, (C) red reflectance, and (D) ir reflectance. The radiance data is not normalized.



(C)



(D)

Figure 2. Red and photographic IR radiances and reflectances plotted against Julian date for a typical soybean experimental plot. Plotted against Julian date are (A) red radiance, (B) ir radiance, (C) red reflectance, and (D) ir reflectance. The radiance data is not normalized.

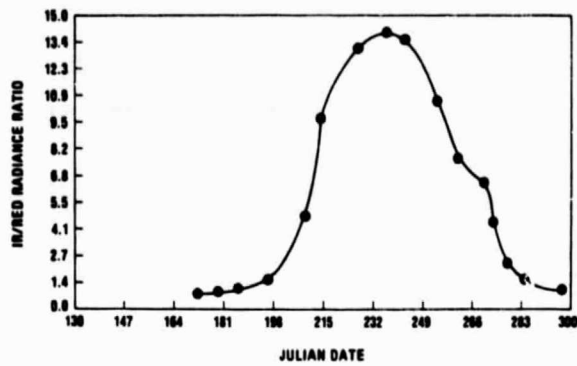
The photographic infrared radiance and reflectance data show an increase with time as the green leaf biomass increases (Figure 2B and 2D). This increases gradually and peaks only to gradually fall off as the growing season continues. The photographic infrared radiance or reflectance asymptotes at green leaf biomass levels two to three times greater than that for the red radiance or reflectance (Gausman et al. 1976; Tucker 1977).

It would be impractical to have to analyze satellite and aircraft data in reflectance units because of the need for many reference readings, assuming that they even could be taken. These types of analyses generally use only radiance data imaged, in the satellite case, for large areas in a small amount of time. This minimizes the need for adjustments to the solar source within the image if atmospheric conditions are constant. Temporal comparisons pose another problem, however, because solar intensity and atmospheric conditions both vary dramatically for the same target scene with time. This leads to the need to develop radiance techniques which (hopefully) effectively compensate for these sources of variability.

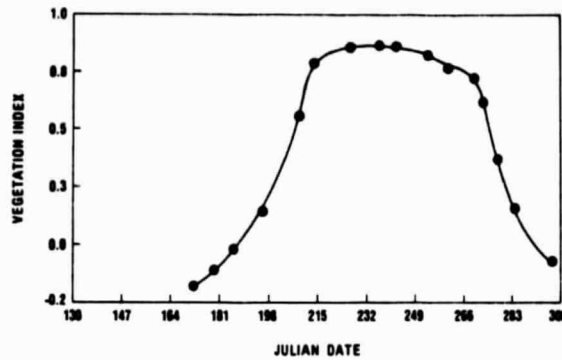
Various techniques have been used in these regards for remotely sensed data. Perhaps the most frequently employed are the ir/red ratio, the VI, and the TVI transformations (Fig. 3).

The ir/red radiance ratio, VI, and TVI all show conclusively that these simple transformations effectively normalize the radiance data and hence adjust

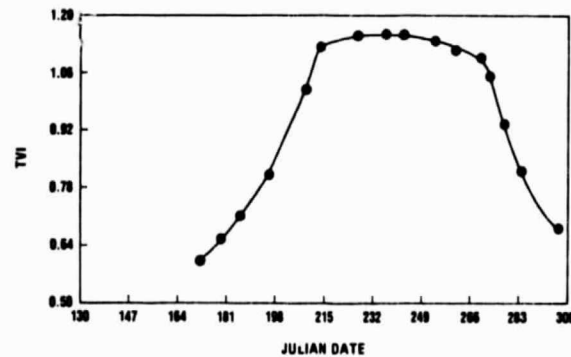




(A)



(B)



(C)

Figure 3. The (A) ir/red radiance ratio, (B) VI, and (C) TVI plotted against Julian date for a typical soy-bean experimental plot. Refer to Figure 2(A) and 2(B) for the radiance data used in this figure. Note how these transformations effectively compensate for variations in solar intensity.

for different levels of spectral irradiance. This is indeed encouraging and suggests that these types of transformations have definite applications for the interpretation of satellite and/or aircraft imagery.

The ir/red radiance ratio (Fig. 3A) is somewhat different than the VI (Fig. 3B) or TVI (Fig. 3C). It is not certain what this difference is caused by and additional research is proceeding here.

Additional research is underway to evaluate the relationship(s) between these types of data, total dry matter accumulation, final harvest yield, biomass, chlorosis, percent cover, and related variables.

#### SUMMARY

1. Ground-collected hand-held radiometer data from the red and photographic infrared spectral regions were successfully used to monitor alfalfa, corn, and soybeans throughout the growing season.
2. The VI and TVI radiance transformations were used to normalize for varying irradiational conditions.
3. The VI approach, as reported in this paper, closely monitors crop growth and development by nondestructively measuring the green leaf dynamics of the crop canopy in question.

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## BIBLIOGRAPHIC DATA SHEET

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| 16. Abstract<br><p>Red and photographic infrared radiance data, collected under a variety of conditions at weekly intervals throughout the growing season using a hand-held radiometer, were successfully used to monitor crop growth and development. The vegetation index transformation was used to effectively compensate for the different irradiational conditions encountered during the study period. These data, plotted against time, quantitatively and qualitatively compare different agronomic treatments by comparing their green leaf biomass dynamics. This approach closely monitors crop growth and development, indicates the promise of ground-based hand-held radiometer measurements of crops, and is based entirely upon spectral inputs.</p> |                                      |                                        |            |
| 17. Key Words (Selected by Author(s))<br>agricultural remote sensing; remote sensing; reflectance studies; crop growth and development; nondestructive plant measurements.                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                            |                                      | 18. Distribution Statement             |            |
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